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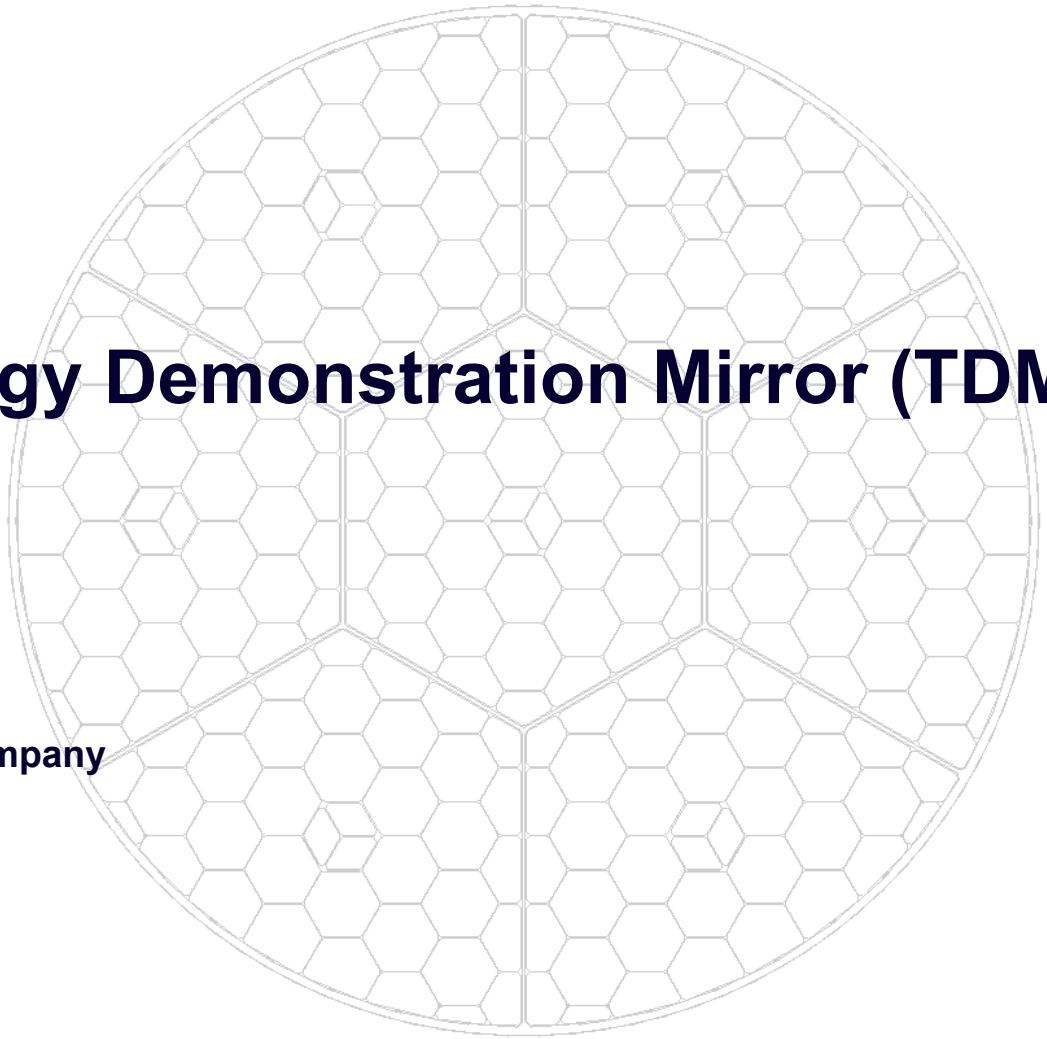

Technology Demonstration Mirror (TDM) for TPF

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Eastman Kodak Company
Sept. 16, 2003

NASA Tech Days

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TDM Program Overview

- **TDM Purpose**
  - Demonstrate that a large, lightweight, space-qualifiable mirror can be finished and coated to achieve the type of mid-spatial performance needed for a coronagraphic TPF
  - Demonstrate that this mirror's surface can be measured to within the accuracy needed for a coronagraphic TPF
  - Demonstrate that this mirror will maintain its performance through mounting, transportation, handling, launch, and operation
- **Kodak's TDM Mirror**
  - Once fabricated, the TDM mirror will provide a major step forward in demonstrating that TPF mid-spatial performance can be achieved on a substrate traceable to the larger TPF mirror

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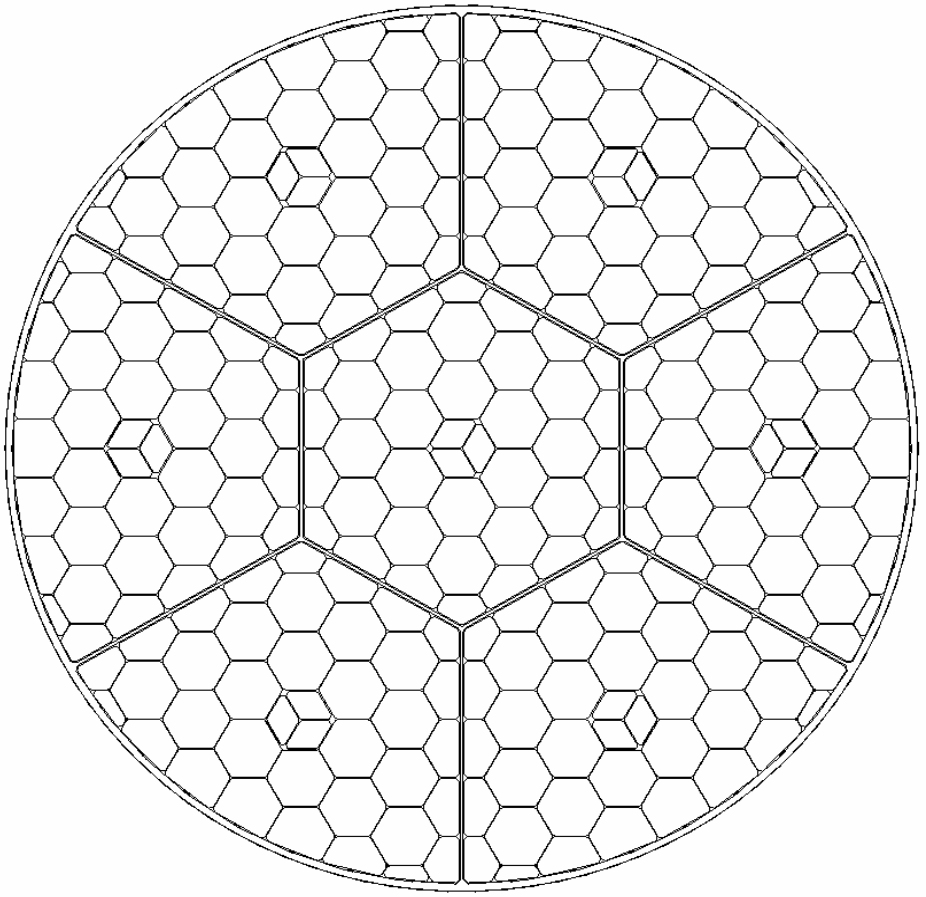
Kodak's Baseline Mirror Design for TDM

- **A preliminary 1.9m off-axis mounted mirror design has been completed which satisfies TDM requirements**
  - Material: Corning ULE™ glass gives thermal stability
  - Sandwich Construction: A lightweight honeycomb core sandwiched between front & back faceplates gives structural efficiency (minimizes mirror depth & mass)
  - Segmented Core: Reduces core fabrication risk and cost significantly
  - Low Temperature Fused (LTF): Gives highly stable all ULE construction
  - Low Temperature Slumped (LTS): Gives efficient near net shape fabrication and uniform faceplate thicknesses. Processing of components as plano prior to LTS results in reduced cost.



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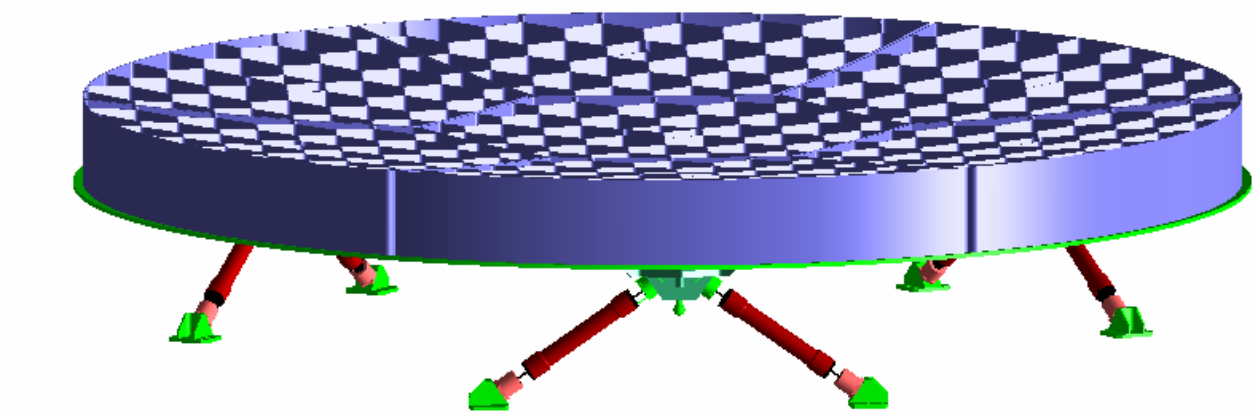
TDM Mounting

- **Mounting and testing large passive mirrors for zero-g applications is not trivial**
- **Kodak has demonstrated a proprietary design to virtually eliminate mount strain**
  - No complex instrumentation required
  - Enables quick integration of PM onto mount struts
  - Readily allows for pre and post strut engagement optical testing



TMD CAD Model
(front plate removed to show core structure)

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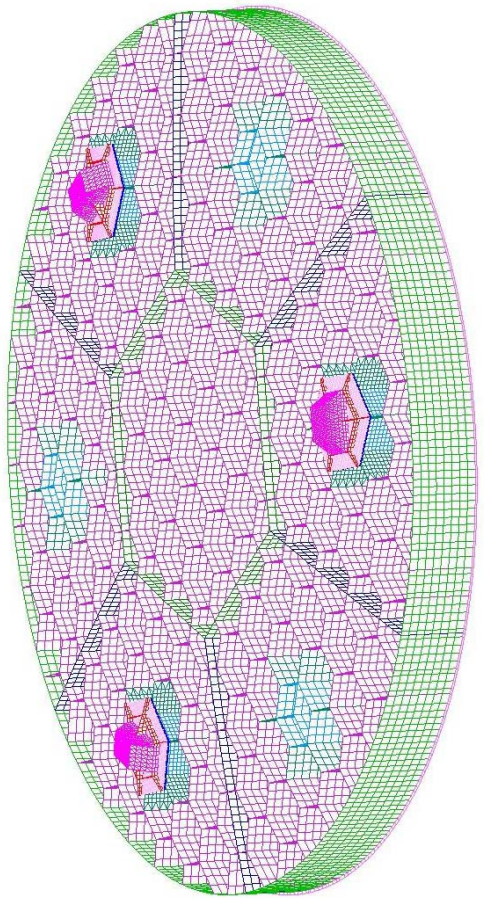
Predicted TDM Performance

- **Areal density**
  - Including mount: 47.5 kg/m^2 (vs. 60 kg/m^2 req.)
  - Mirror alone: 42.5 kg/m^2
- **Stiffness**
  - First free mode: 304 Hz (vs. 200 Hz req.)
  - First mounted mode: 87 Hz (vs. 85 Hz req.)
- **On-orbit surface figure**
  - Low freq (λ > 40cm): 10 nm rms
  - Mid freq (40cm > λ > 2cm): 4.7 nm rms
  - High freq (2cm > λ > 1mm): 1.4 nm rms
- **Stress margins of safety are positive in all mirror and mount components**



TDM Finite Element Model (back plate removed to show core details)

Key Innovations in Lightweight Mirror Technology

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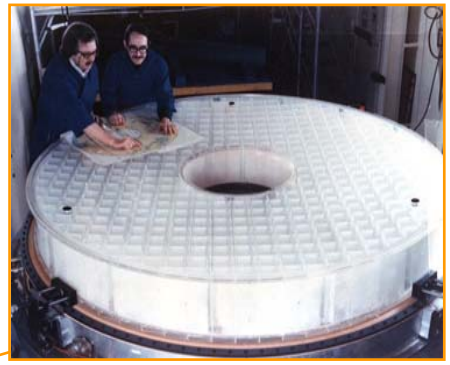
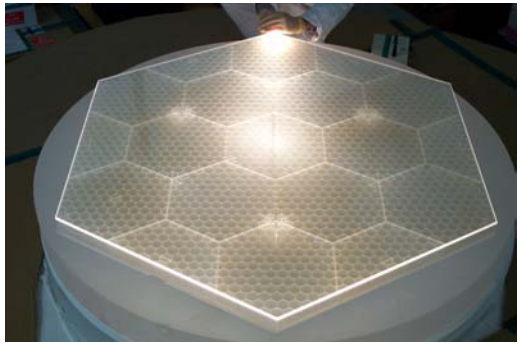
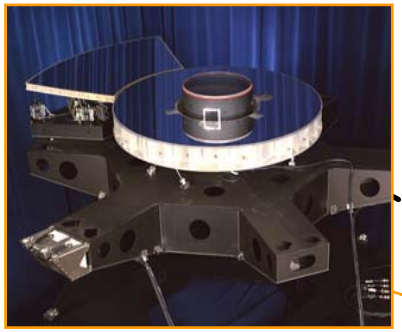


Hubble Space Telescope
BU 2.5m Primary Mirror

Advanced Demonstrator
0.6m LTF/Pocket-milled
(scaled to 2.5 meters)



AMSD - Class Technology
1.4 meter (scaled to 2.5 meter)



AOSD Telescope
Segmented 2.6m Primary Mirror

Areal Density (kg/m²)

200
100
50
25

1980
1990
2000

TDM
(1.9m)

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TDM Fabrication Outline

- **Select ULE™ glass**
- **Shine face plates and core segment solids**
- **Waterjet cut core segments**
- **Assemble and LTF the plano blank**
- **Prepare plano blank surfaces for LTS**
  - Thin front plate
  - Thin and shine back plate at final thickness
- **LTS blank to near net shape over an aspheric mandrel**
  - Maintains uniform face-sheet thickness
- **Final mirror processing**
  - Shape and figure front surface
- **Coat**
- **Mount**

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TDM Processing

- **TDM builds on Kodak's significant R&D investment in off-axis segment processing**
  - Kodak identified technology required to process high volume off-axis segments several years ago
  - Kodak has been investing in these technologies
  - These technologies enable off-axis aspheres with extremely small mid spatial frequency figure errors

- **TDM will demonstrate that these processing technologies will meet the needs for coronographic missions**

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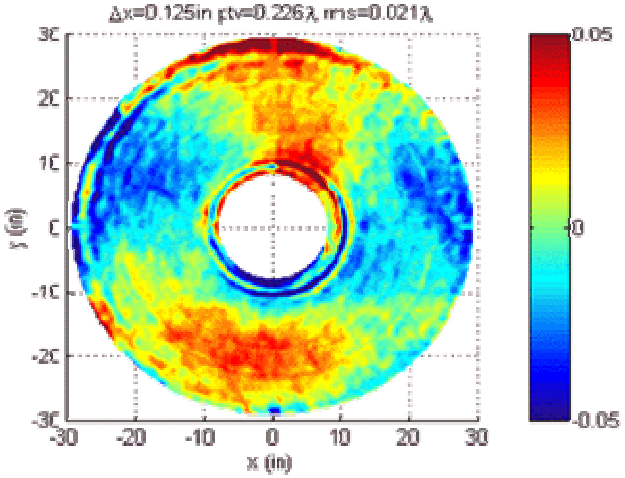
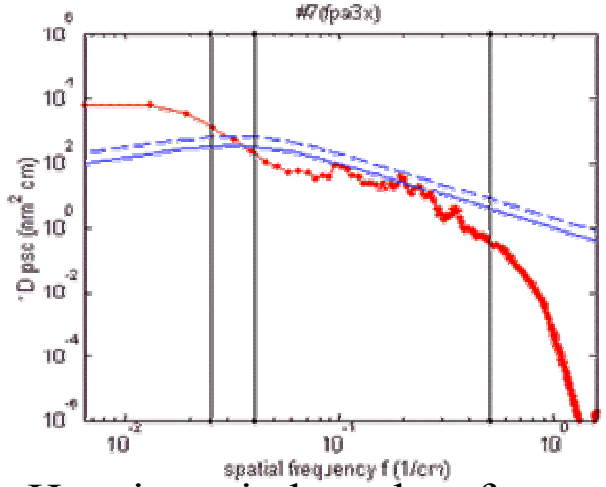
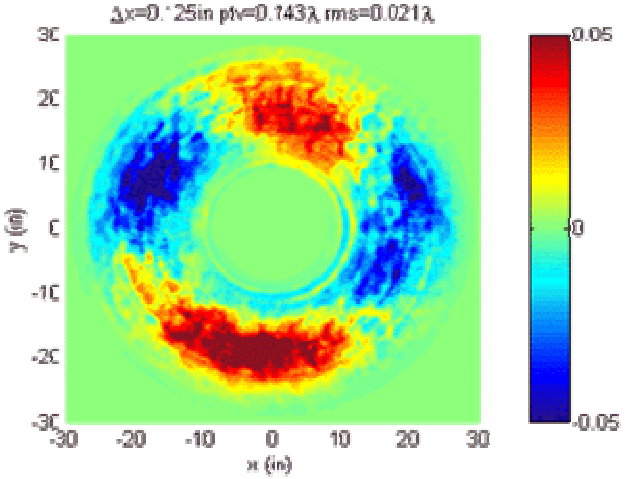
Existing Kodak Processes Yield Superb Performance in Mid-Spatial Bands



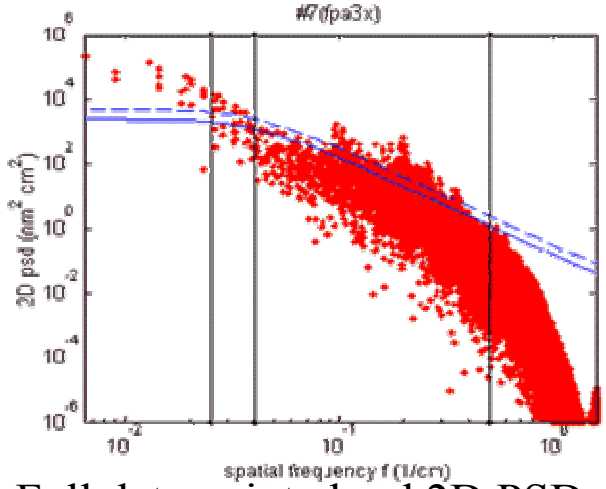
Smoothed Surface Figure



Hanning windowed surface array



Radially averaged PSD



Full data point cloud 2D PSD data

Dashed blue line on PSD plots is TDM requirement, solid blue line is goal.

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TMD Surface Figure Measurements

- **Baseline metrology methods**
  - Low & mid-spatial frequencies ($\infty > \lambda \geq 2$ cm)
    - Full aperture interferometry
    - 1 M-pixel detector (meets 5x Nyquist goal)
    - 2 element Offner-type null lens
  - High-spatial & micro roughness ($2 \text{ cm} > \lambda > 1$ μm)
    - Sub-aperture surface profiling
    - Chapman Instruments profiler
- **Gravity quilting of front plate over core cells**
  - Kodak plans to use an analytical backout for 1-g quilting effects
  - Currently carrying 10% finite element modeling uncertainty in budget (can be reduced, if needed, through detailed model correlation)
    - LSF: 0.63 nm-rms
    - MSF: 0.34 nm-rms
    - HSF: 0.002 nm-rms

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TDM Figure Error Budget

- **A surface figure error budget was assembled for TDM to verify that the design can be manufactured**
- **The budget addresses the 3 freq bands of interest and includes:**
  - Manufacturing errors from mirror processing, test, coating, and mounting
    - Mirror polishing residuals
    - Coating strain (uniform & nonuniform)
    - Mirror test set uncertainties (optical & mechanical)
    - Mount induced strain
    - Mounted mirror test set uncertainties (including analytical backouts)
  - On-orbit operational errors
    - Thermal performance (mirror CTE homogeneity)
    - Material temporal stability (invar & adhesives)
- **The budget shows that TDM requirements can be satisfied by the Kodak design and manufacturing approaches**

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Kodak TDM Study Conclusions

- **The TDM mirror fabrication requirements are achievable**
  - Risks are understood and manageable
- **A baseline mirror and mount design has been established**
  - Successful analytical verification has provided early risk mitigation
- **Requirements flow-down understood**
  - Error budgets and sensitivities show that requirements can be met